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Soil conditioning index and soil organic carbon in the Midwest and southeastern United States

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Abstract: Calibration of the soil conditioning index (SCI) to a diversity of field studies with known changes in soil organic carbon (SOC) would improve the usefulness of the SCI by the USDA Natural Resources Conservation Service to assess the environmental services provided by agricultural land stewardship. Our objectives were to (1) calibrate SCI scores against SOC from published field studies in the Midwest and (2) compare the calibration with a recently derived calibration from the southeastern United States. We found that SOC sequestration (at 25 ± 6 cm [10 ± 2 in] depth) could be reliably related to SCI across a diversity of studies in the region using the regression slope: 4.52 Mg C ha^{-1} SCI^{-1} (2.02 tn ac^{-1} SCI^{-1}), which translated into a rate of 0.35 ± 0.06 Mg C ha^{-1} y^{-1} SCI^{-1} (314 ± 57 lb ac^{-1} yr^{-1} SCI^{-1}), which is the mean ± standard error of 18 slope estimates. Calibration slopes did not vary significantly between the Midwest and southeastern United States, resulting in a combined calibration of 0.29 ± 0.03 Mg C ha^{-1} y^{-1} SCI^{-1} (255 ± 30 lb ac^{-1} yr^{-1} SCI^{-1}), which is the mean ± standard error of 49 slope estimates. The calibration of SCI scores to SOC will allow SCI to become a quantitative tool for natural resource professionals to predict SOC sequestration for farmers wanting to adopt conservation practices.

Key words: conservation tillage—crop rotation—modeling—no-tillage—organic matter

Rapid and reliable assessments of the potential of different agricultural management systems to sequester soil organic carbon (SOC) are needed to promote conservation and help mitigate greenhouse gas emissions. Several recent regional literature reviews have documented the potential of conservation agricultural systems to sequester SOC (West and Post 2002; VandenBygaart et al. 2003; Franzluebbers 2005; 2010; Johnson et al. 2005; Liebig et al. 2005). Unfortunately, results appear to be site, soil, and cropping system specific, resulting in uncertainty of how to predict the effect of management in different environments (Varvel 1994; Dick et al. 1998; VandenBygaart et al. 2002; Venterea et al. 2006; Gál et al. 2007).

The soil conditioning index (SCI) is a relatively simple model to parameterize and is currently used by the USDA Natural Resources Conservation Service to predict relative changes in SOC. However, it is currently only used as a nonquantitative tool to determine the trend in SOC in response to various management options (Cox 2008). The SCI is based on three important conditions: (1) organic material grown or added to the soil, (2) field operations that alter organic material placement in the soil profile and that stimulate organic matter breakdown, and (3) erosion that removes and sorts surface soil organic matter.

The SCI has been scientifically evaluated in only a relatively small number of studies. Hubbs et al. (2002) reported a coefficient of determination of 0.56 (n = 19) for SCI against change in SOC concentration in the western United States and 0.76 (n = 14) in the eastern United States. Unfortunately, SOC was evaluated only on a concentration basis (mg g^{-1} [%]) and not on an area basis (Mg ha^{-1} [tn ac^{-1}]) due to lack of information on bulk density. Changes in SOC will likely be most meaningful to the diversity of parties interested in its change (e.g., scientists, brokers, and policy makers) when reported as Mg ha^{-1} y^{-1} (tn ac^{-1} yr^{-1}) so that estimates can be summarized across various landscape features, farm units, and time periods.

When evaluated on farm fields of the Southern High Plains in Texas, SCI was significantly related (but only weakly) to differences in SOC as a result of different land uses (e.g., inversion versus no-tillage, dryland versus irrigated, cropping versus grassland) (Zobeck et al. 2007). On a multiple-year experiment in Colorado, SCI from five different irrigated cropping systems under conventional and no-tillage was highly related to SOC (Zobeck et al. 2008). From the Solutions to Environmental and Economic Problems (STEEP) project in the Pacific Northwest, SCI values gradually increased from strongly negative values in 1975 to neutral to positive values in 2005 with progressive adoption of improved conservation technology and farming systems (Kok et al. 2009). At three locations in the southeastern United States, SCI and the Environmental Policy Integrated Climate (EPIC) model were effective at differentiating potential SOC changes with adoption of increasingly diversified rotations with cotton (*Gossypium hirsutum* L.) under no-tillage against monoculture cotton under conventional tillage (Abrahamson et al. 2007). All of these studies indicate that SCI should be related to changes in SOC with adoption of conservation compared with conventional management, but quantitative relationships with actual field data are scant.

Recently, calibration of SCI against SOC content was determined for a diversity of field studies in the southeastern United States (Franzluebbers et al. 2010). From a total of 31 studies in the region, each unit change in SCI was calibrated to a SOC sequestration rate of 0.25 ± 0.04 Mg carbon (C) ha^{-1} y^{-1} (220 ± 34 lb ac^{-1} yr^{-1}). There was concern raised that the calibration in the southeastern United States might be different than other regions due to the widespread use of low-residue producing cotton and highly disturbed condition with peanut (*Arachis hypogaea* L.) harvesting, even with conservation management. Therefore,

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Table 1
Locations and conditions for comparing soil organic carbon and soil conditioning index in the Midwest United States.

Experiment Number	Location (state/county)	Soil	Management variables	Source
1	Iowa/Chickasaw	Floyd L	Tillage	Karlen et al. (1998)
2	Illinois/Champaign	Thorp SiL	Tillage	Yang and Wander (1999)
3	Illinois/Dekalb	Drummer SiCL	Tillage	Wander et al. (1998)
4	Illinois/Pike	Ipava SiL	Tillage	Wander et al. (1998)
5	Illinois/Warren	Muscatune SiL	Tillage	Wander et al. (1998)
6	Illinois/Will	Blount SiL	Tillage	Mielke et al. (1986)
7	Indiana/Tippecanoe	Chalmers SiCL	Tillage, rotation	Elliott et al. (1994)
8	Kentucky/Fayette	Maury SiL	Tillage, fertilizer	Blevins et al. (1977), Elliott et al. (1994), Ismail et al. (1994), Six et al. (2000)
9	Michigan/Barry	Kalamazoo L	Tillage, crop	Robertson et al. (2000), Six et al. (2000)
10	Michigan/Clinton	Capac L	Tillage, cover crop	Pierce et al. (1994)
11	Minnesota/Dakota	Waukegan SiL	Tillage, residue	Clapp et al. (2000)
12	Minnesota/Waseca	Nicollet CL	Tillage	Mielke et al. (1986)
13	Minnesota/Waseca	Webster CL	Tillage	Mielke et al. (1986)
14	Missouri/Boone	Mexico SiL	Tillage, rotation	Buyanovsky and Wagner (1998)
15	Nebraska/Lancaster	Crete SiCL	Tillage	Eghball et al. (1994)
16	Ohio/Coshocton	Coshocton SiL	Tillage	Rhoton et al. (2002)
17	Ohio/Wayne	Wooster SiL	Tillage, rotation	Lal et al. (1994), Dick et al. (1998), Six et al. (2000)
18	Wisconsin/Grant	Rozetta SiL	Tillage	Karlen et al. (1994)

Notes: L = loam. SiL = silt loam. SiCL = silty clay loam. CL = clay loam.

further calibration is needed in other regions with different cropping systems.

We hypothesized that different relationships between SCI and SOC derived from field studies would be obtained from the Midwest and southeastern US regions due to differences in climate, soil type, and prevalent management systems. Our objectives were to (1) calibrate SCI scores against published SOC data derived from field experiments under various management systems in the Midwest and (2) compare the calibration curves between the Midwest and southeastern US regions.

Materials and Methods

Soil organic C content data (Mg C ha^{-1}) from numerous field studies comparing tillage systems primarily, but also comparing crop rotation, fertilizer, and cover crop systems throughout the Midwest were obtained from original studies reported in the review of the region by Johnson et al. (2005). Index scores of SCI were predicted using Revised Universal Soil Loss Equation 2 (RUSLE2) version 1.26.6.4 for locations and management conditions that closely matched those from published reports. Published reports used to obtain SOC data and the conditions for SCI scoring are in table 1. A total of 64 observations from 18 studies were assembled from 10 states in the Midwest. Soil organic C data and SCI scores for 130 observations from 8 states in the southeastern United States were previously reported in Franzluebbers et al. (2010). In the Midwest, SOC content was regressed upon SCI scores for (1) individual locations with multiple management conditions and (2) all data with state and study as blocking criteria. The significance of slopes was tested between continuous corn (*Zea mays* L.) and more diverse rotations (i.e., corn–soybean [*Glycine max* (L.) Merr.], corn–oat [*Avena sativa* L.]–clover, corn–wheat [*Triticum aestivum* L.]–soybean). Significance of regressions was declared at $p \leq 0.05$. Summarized relationships between regions were compared with a *t* test.

Results and Discussion

Data from the Midwest were well distributed among 10 states, with no state accounting for more than 20% of the data (table 2). Table 2 provides summary statistics for data collected within three arbitrary zones and across states. The stock of SOC was much higher in the Midwest (58.8 ± 21.4 Mg C ha^{-1} [26.2 ± 9.6 tn ac^{-1}]) (table 2) than in the southeastern United States (28.5 ± 12.2 Mg C ha^{-1} [12.7 ± 5.4 tn ac^{-1}]) (Franzluebbers et al. 2010). This was partly due to the slightly greater sampling depth in the Midwest (25 ± 6 cm [10 ± 2 in]) than in the southeastern United States (20 ± 5 cm [8 ± 2 in]), but also due to inherent differences in soil-forming factors between the two regions (Jenny 1980; Rhoton et al. 2002). Soils tested in the Midwest were Mollisols (n = 10) and Alfisols (n = 8), while in the southeastern United States they were Ultisols (n = 23), Alfisols (n = 3), Inceptisols (n = 2), Mollisols (n = 2), and Vertisols (n = 1). Field studies also tended to be conducted for longer periods of time in the Midwest (15 ± 8 years) than in the southeastern United States (10 ± 6 years). Variations in characteristics among three zones in the Midwest were not large, although stock of SOC and SCI scores tended to be lowest in the south and length of investigation tended to be lowest in the north (table 2).

When pooling all pairs of SOC data and SCI scores (n = 64) together across 18 studies in the Midwest as a simple scatter plot, a weak (r^2 = 0.03) and nonsignificant relationship (p = 0.17) resulted. However, when data were blocked according to the 18 studies (which resulted in different absolute values of SOC due to differences in sampling depth, site history, soil texture, climatic conditions, etc.) (figure 1), a strong (r^2 = 0.95) and significant relationship (p < 0.001) between SOC and SCI resulted in the following equation:

$$\text{SOC (Mg ha}^{-1}) = 59.4 + 4.52 \text{ (SCI)} \quad , \qquad (1)$$

Table 2
Summary statistics of soil conditioning index scores, soil organic carbon data, and associated study characteristics in three zones.

	Zone			
Variable	North	Middle	South	All
Number of observations	20	30	14	64
Soil conditioning index score				
Mean	0.20	0.02	−0.11	0.05
sd	0.56	0.58	0.84	0.64
Minimum	−0.9	−1 .0	−2.0	−2.0
Maximum	1.0	0.9	0.9	1.0
Sampling depth (cm)				
Mean	24.1	24.1	27.1	24.7
sd	7.0	4.9	4.7	5.7
Minimum	14	15	20	14
Maximum	30	30	30	30
Years of management				
Mean	10.7	17.8	17.0	15.4
sd	2.4	9.9	5.6	8.0
Minimum	6	6	11	6
Maximum	13	34	25	34
Soil organic carbon (Mg ha^{-1})				
Mean	63.5	60.6	48.0	58.8
sd	30.1	17.0	8.7	21.4
Minimum	16	26	32	16
Maximum	107	110	57	110

Notes: North = Michigan, Minnesota, Wisconsin. Middle = Illinois, Indiana, Iowa, Ohio. South = Kentucky, Missouri, Nebraska. sd = standard deviation.

in which the slope estimate had a standard error of 1.16 Mg ha^{-1} SCI^{-1} (0.52 tn ac^{-1} SCI^{-1}). Since length of field-study investigation varied from 6 to 34 years, the slope estimate had to be further adjusted by computing the slope for each individual study and dividing by the number of years of experimentation for that study (table 3). With this calculation, the rate of SOC sequestration per unit of SCI was 0.35 ± 0.06 Mg C ha^{-1} y^{-1} SCI^{-1} (314 ± 57 lb ac^{-1} yr^{-1} SCI^{-1}) (mean ± standard error of 18 observations). This calibrated slope was not significantly different (p = 0.14) from that derived for the southeastern United States (0.25 ± 0.04 Mg C ha^{-1} yr^{-1} SCI^{-1} [220 ± 34 lb ac^{-1} yr^{-1} SCI^{-1}, which represents mean ± standard error of 31 observations]) (Franzluebbers et al. 2010). Using equation 1, a cropping system with SCI score of –0.6 (one standard deviation lower than the mean) would be predicted to have SOC content of 56.1 Mg ha^{-1} (25.0 tn ac^{-1}), while a cropping system with SCI score of +0.7 (one standard deviation greater than the mean) would be predicted to have SOC content of 62.0 Mg ha^{-1} (27.7 tn ac^{-1}). Implemented over 15.4 y (mean value of dataset) (table 2), SOC sequestration rate of improved compared with conventional management would be 0.38 Mg C ha^{-1} y^{-1} (342 lb ac^{-1} yr^{-1}). In a review of 44 pairs of SOC data between conventional and no-tillage in the Midwest, SOC sequestration rate was 0.40 ± 0.09 Mg C ha^{-1} y^{-1} (359 ± 82 lb ac^{-1} yr^{-1}) (Johnson et al. 2005); thus, the rate of 0.38 Mg C ha^{-1} y^{-1} with a difference of 1.3 SCI units was consistent with field studies.

When data were sorted by crop rotation, the rate of SOC sequestration under no-tillage compared with moldboard plowing was not different (p = 0.38) between studies under continuous corn (0.31 ± 0.14 Mg C ha^{-1} y^{-1} [277 ± 125 lb ac^{-1} yr^{-1}]) (mean ± standard error among 15 observations) and corn rotated with soybean (0.51 ± 0.14 Mg C ha^{-1} y^{-1} [455 ± 125 lb ac^{-1} yr^{-1}]) with n = 8. The SCI scores averaged -0.6 under moldboard plowing and +0.7 under no-tillage with continuous corn and –0.5 under moldboard plowing and +0.5 under no-tillage with rotated corn. The regression of SOC on SCI was not different (p = 0.75) between cropping systems, in which calibration rates were 0.34 ± 0.09 Mg C ha^{-1} y^{-1} SCI^{-1} (304 ± 80 lb ac^{-1} yr^{-1} SCI^{-1}) under continuous corn and 0.32 ± 0.07 Mg C ha^{-1} y^{-1} SCI^{-1} (286 ± 62 lb ac^{-1} yr^{-1} SCI^{-1}) under rotated corn.

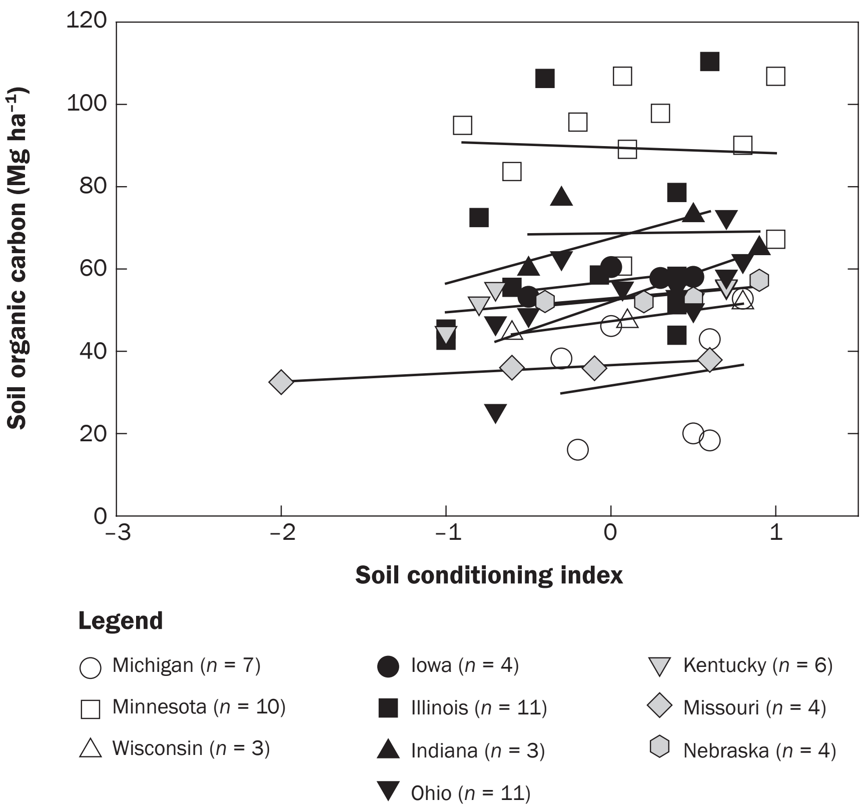
Since calibration slopes were not different (p = 0.14) between the Midwest (0.35 ± 0.06 Mg C ha^{-1} y^{-1} SCI^{-1} [314 ± 57 lb ac^{-1} yr^{-1} SCI^{-1}]) and the southeastern United States (0.25 ± 0.04 Mg C ha^{-1} yr^{-1} SCI^{-1} [220 ± 34 lb ac^{-1} yr^{-1} SCI^{-1}]), data could be reasonably combined to yield an overall calibration of 0.29 ± 0.03 Mg C ha^{-1} y^{-1} SCI^{-1} (255 ± 30 lb ac^{-1} yr^{-1} SCI^{-1}) (n = 49). It should be noted that the conditions under which this calibration was established were sampling depth of 22 ± 6 cm (9 ± 2 in) and length of investigation of 11 ± 7 y (mean ± standard deviation). Use of the calibration estimate should be kept within those conditions to be most valid.

Our analysis did not support a recommendation to have a separate calibration of SCI against SOC in the Midwest compared with the southeastern United States. Only with additional original field data indicating otherwise would a separate calibration between the two regions be necessary.

Calibration of SOC content on SCI scores from long-term field studies in other regions has been rarely investigated. We calculated a calibration slope of SOC (10 cm [4 in] depth) on SCI in 12 agroecosystems in the Southern High Plains of Texas of 0.74 Mg C ha^{-1} SCI^{-1} (661 lb ac^{-1} SCI^{-1}) from data reported in Zobeck et al. (2007), in which SCI was 0 ± 0.9. The relationship was equally weak (r^2 = 0.09) as in the unstructured Midwest scatter plot, but it suggested that calibration slope of SOC on SCI may be lower in drier than in wetter regions. Plausible explanations for the difference in calibration slopes might be lower crop biomass production and limited amount of C available in plant residues to contribute to SOC sequestration. However, decomposition of available organic matter could be expected to be lower under dry than wet conditions.

In Colorado, a calibration slope of 3.38 Mg C ha^{-1} SCI^{-1} (1.51 tn ac^{-1} SCI^{-1}), with r^2 = 0.76, was developed from a 7 y evaluation (0.48 Mg C ha^{-1} y^{-1} SCI^{-1} [431 lb ac^{-1} yr^{-1} SCI^{-1}]) of tillage and crop rotation systems from data reported in Zobeck et al. (2008), in which SCI was 1.0 ± 0.4. Crop residue production was high (mean of 6.2 Mg ha^{-1}) in this dry climate (with supplemental irriga-

Figure 1
Relationship of soil organic carbon to soil conditioning index score from 18 studies in 10 states of the Midwest United States. Data are plotted for the 10 states for simplicity, but regression slopes were obtained for the 18 studies to yield equation 1.



tion) and this may have contributed to the high calibration slope. Since SCI scores were all >0 in this study, the calibration slope may have also been elevated should the relationship between SOC content and SCI score not be truly linear but instead exponential as noted by Abrahamson et al. (2007). Further research is needed to better understand the shape of calibration slopes under different soil and climatic conditions, as well as with different lengths of investigation.

Absolute SCI of a single cropping system at a specific location will not necessarily be revealing for SOC sequestration. As can be seen in the data in figure 1, significant SOC sequestration would have occurred in some cropping systems with SCI score of 0 compared to a less desirable cropping system with a score of −2. There is a need to establish a baseline management condition so that a change in SOC can be expected. If the baseline condition were to have a highly negative SCI score, then even a minimal conservation management technique would likely improve SOC sequestration. If, however, the baseline condition were at an acceptable level, then only more rigorous conservation measures could be expected to achieve significant SOC sequestration in the future.

Table 3
Regression of soil organic carbon (SOC) content against the soil conditioning index (SCI) in individual studies of the Midwest United States.

Experiment number	Number of observations	Intercept (Mg C ha^{-1}) (SOC at SCI = 0)	Slope (Mg C ha^{-1} SCI^{-1})	Standard error of slope (Mg C ha^{-1} SCI^{-1})	Rate of SOC sequestration (Mg C ha^{-1} y^{-1} SCI^{-1})
1	4	57	4.5	3.7	0.35
2	2	108	4.1	na	0.39
3	2	50	4.2	na	0.70
4	2	77	5.1	na	0.48
5	2	44	0.9	na	0.08
6	3	58	2.7	1.8	0.28
7	4	69	0.5	8.2	0.05
8	6	53	3.4	2.0	0.22
9	4	43	8.9	5.6	0.99
10	3	17	3.9	2.4	0.28
11	6	92	0.8	4.2	0.06
12	2	60	7.0	na	0.64
13	2	107	−0.0	na	−0.01
14	4	37	2.0	0.3	0.08
15	4	53	3.6	1.9	0.33
16	2	42	23.3	na	0.69
17	9	55	8.4	4.8	0.29
18	3	47	5.3	0.7	0.44
Mean/sum	64	59	4.9	na	0.35 ± 0.06

Note: na = not applicable.

Summary and Conclusions

Calibration of SOC sequestration on SCI scores for the Midwest was 0.35 ± 0.06 Mg C ha^{-1} y^{-1} SCI^{-1} (314 ± 57 lb ac^{-1} yr^{-1} SCI^{-1}), which was not different from that of the southeastern United States, and therefore, a combined calibration was 0.29 ± 0.03 Mg C ha^{-1} y^{-1} SCI^{-1} (255 ± 30 lb ac^{-1} yr^{-1} SCI^{-1}; mean ± standard error of 49 slope estimates). Most of the SCI calibration scores in the Midwest were in the range of –0.6 to +0.7. As was noted in the southeastern United States, further work is needed in the Midwest to broaden the calibration to include much higher SCI scores with highest conservation measures. Data do not support development of separate calibration curves to relate SCI to SOC changes in these two relatively moist regions, but calibration curves in drier regions have yet to be fully evaluated. The successful calibration of SOC content on SCI scores will allow SCI to become a more quantitative tool in predicting SOC content for farmers wanting to adopt conservation practices.

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